Research advance in forest restoration on the burned blanks

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Abstract: How to restore the destroyed forest after forest fire is a key question that man must face. This paper reviewed the research situation and history on the forest restoration burned blanks and summed up the research methods used into four scales: seed-bank scale, community scale, ecosystem scale and landscape scale. The new technologies such as GIS & Remote Sensing used to vegetation restoration were also summarized. The strategies and developing trend of vegetation restoration research on burned blanks were discussed.

Keywords: Burned blanks; Forest restoration; Research advance; Questions and countermeasures

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Introduction

In the field of ecological restoration, "restoration" means the activity of renovating destroyed ecosystem, or the re-appearance of a natural ecosystem which can self-maintain and self-adjust, but may not always revert to the original state (Cen *et al.* 1999). Based on the ecological succession theory, ecosystem has capacity to self-heal after being destroyed, namely all degenerative ecosystem can resume under sufficient time and condition. So the essence of ecological restoration is to artificially conquer or eliminate the factors that can restrict the development of ecosystem, and to succeed in resuming derogating ecosystem as soon as possible (at least shorten natural restoration). Forest vegetation restoration is one of the most important aspects of ecological restoration, and human interference can promote vegetation resuming in short period (Peng 2000). Generally speaking, vegetation restoration means not only natural vegetation restoration but also human planting.

Many factors may induce vegetation destruction. Forest fire is an important reason causing forest shrinkage in the world. According to the statistics in 47 nations (accounting for 53.9 % of world forest area) by United Nations Food and Agricultural Organization (UNFAO 1992), the average fire area every year was 673×10^4 hm^2 from 1881 to 1990, accounting for 0.47% of world forest area. From 1950 to 1997, there were 14.3 thousand forest fires occurred in china, and the burned area of forest reached 82.2×10^4 hm^2 (Shao 2000).

Forest fire is not a negligible factor in forest ecosystem. On one hand, it destroys the original forest. Rapid change in the atmosphere, water and soil will occur after a heavy fire. Mineral cycling and energy flow will also be disturbed (Zhang 1994); On the other hand, it is an indispensable ecological factor in nature. Certain frequency and intensity of fire can help to maintain forest ecological balance and biological diversity. Regardless of the positive and negative function of forest fire, vegetation restoration on burned blank is an important problem to be studied. Much attention has been paid on the relationship between forest landscape structure and vegetation restoration (Turner 1997). A great number of studies have been made on different vegetation restoration. This paper mainly focuses on the studies of forest restoration on burned blank.

Research history

The research on forest restoration in burned blanks started as early as 19th century considered that the history of research about ecological influence of forest fire on vegetation in North-America was 250 years. In 1947, Grren summarized the influence of forest fire in Middle-South America, and used the concept of "fire succession" and "Fire Sub-climax" (Shu 1993). Even before the 1960s, Dale Taylo, an American ecologist who studied the changes of species composition in every phase of forest restoration after forest fire, had found that young-wood species of natural restoration had the largest difference, and that these species would replace the burned out forest in a few years after forest fire. In the 1970s, Birthill regarded forest fire as an important factor in forest ecology, and published the collected papers based on the research of forest fire and forest ecology in 1974. In the book he mentioned the influence of fire on the temperate forest. Hanes (1971), after investigation in the frutex-cluster in California where fire happens frequently, found that the frutex-cluster in this area had great capability to adapt forest fire and it could

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quickly regenerate in way of seed-bud sprouting. He regarded such the succession as "auto-succession" in which the frutex-cluster can promptly recover, become dominant species, and maintain for a certain period, and regarded forest fire as the "adjuster" of this succession. Gill (1981) thought that the plant adaptability to forest fire could be embodied from the following two aspects: 1). Plant has the agamogenetic capability; 2). Forest fire can promote florescence, seed-release and seed-bourgeoning. Cormack *et al.* (2001) pointed out that forest ecosystem restoration after violent forest fire must have feasible climate condition. Through the analysis of the tree-growth-ring climatology, Savagede (1991) considered that pine trees had very short natural restoration time after violent forest fire in Southwest of America and the frequency of the restoration was also low, for there were only two years that the climate was suitable to pine restoration and growth in the whole 20th century. Moore (1996) and Zackrisson *et al.* (1996) put forward that forest burned giblets such as carbon can affect forest succession and soil ecosystem process.

In the summer of 1988, a conflagration occurred in Yellowstone National Park, whose total area was 9 000 km^2, and burned 2 913.7 km^2 of forest. The loss by this fire was disastrous. However it provided a chance to study ecological disturbance for biologists and geographers. By studying the case of Yellowstone National Park many experts found that forest fire had an important effect on nutrition cycling in forest community and could promote the release of nutrients in organism called "second nutrition conservation mechanism". Herbage plant community can absorb nutrition and participate in re-cycling at faster speed, compared with wood-plant community. Thus, after a wood-plant community suffered forest fire, the burned blank is firstly occupied by herbage plant community, after then it gradually evolves into wood-plant community (Romme *et al.* 1990).

With the development of advanced technology and the landscape ecology, Geographic information systems (GIS) have been used in Yosemite National Park for fire research and management applications since the early 1980s (Van 1991). A GIS model was used for the fire return-interval departure analysis in the new fire management plan for the park. According to the result, people can know the dynamic of the forest landscape.

In China the comprehensive study of forest restoration on burned blank was carried out in Daxing'an Mountains after a conflagration occurred in May of 1987. Daxing'an Mountains forest region is an important timber production base in China. Serious forest fire frequently happens in this forest region. A conflagration occurred in the north area of Daxing'an Mountains on May 6, 1987, which brought about a total burned area of 1.33x10^6 hm^2, including forest area of 1.14x10^6 hm^2, and the area-suffered injury was 8.7x10^5 hm^2. The loss from this fire was disastrous. Detailed investigations on natural factors such as burning severity, forest types, and soil were conducted after the fire, and quite a few research papers and reports on quickly restoring forests of this region were published by both Chinese and foreign scientists. Many methods and technologic skills of vegetation restoration were proposed.

Research methods

The studies on forest restoration in burned blanks mostly started from two aspects. One is the environment factors that influence the forest restoration, such as, topography, soil, fire intensity and climate. The other is the character of the forest in the burned blanks. Generally we can study form four scales such as seed-bank scale, community scale, ecosystem scale and landscape scale.

Seed-bank scale

Seed-bank is the basic unit of species existence and evolution, as well as the basic component of ecosystem and biological community (Zhong 1992). Most of the study was about the quantitative change (species diversity), spatial distribution and falling character of seeds on the burned blanks. Finding out the change of the species habit after fire is the most important. In china, Shan *et al.* (1990) studied the relationship between the fruiting law and the characteristics of long and short branches of *Larix gmelinii*, and tried to predict the fruiting by investigating its flower and bud. Liu *et al.* (1995) studied the relationship between the blossom and growth of *Pinus sylvestris* var. *mongolica*. Zheng *et al.* (1986) delineated 3 fire return intervals for the Daxing'an Mountains forest region, according to the forest fire data from 1971 to 1980, and discussed forest succession and restoration approach through analyzing the frequency of forest fire and the adaptability of tree-seed to the fire; meantime, based on the fire resistance of tree species, he put forward five types of tree-seed regeneration strategies of five species: invading, escaping, avoiding, resisting, and enduring. All the study will conduct people how to restore the forest by natural succession or by artificial disturbance. Species diversity and change was a topic after fire for intrigued biologists. The fire frequency was an important affecting factor to species diversity and change. Some experts have attempted to quantify the effect. Schwilk *et al.* (1997) analyzed the limitation of the use of intermediate disturbance hypothesis on the study of species diversity and also gave us an explanation of how to use it. Fire also influences the species stability. Qiu (1997) studied the relation between the stability of the *Larix gmelini* population and the fire disturbance. The result showed that the population of *Larix gmelini* was able to keep stable depending on its stronger fire resistance, post-fire resilience and self-resilience. The fire resistance of population is related to the fire disturbance regime. The post-fire resilience and self-resilience are related to the last fire regime. The post-fire resilience had shown the following sequences: high severity > middle severity > low severity, and the rank of self-resilience is middle severity > high severity > low severity. This conclusion indicated that suitable fire distur-

bance was useful for the stability of the *Larix gmelini* (Qiu *et al.* 1997). It often fosters new plant growth and wildlife populations often expand. Keeley (1977) undertook a study of seed production, seed storage in the soil, and seedling production after fire to determine the factors influencing seed regeneration in a congeneric pair of species of *ceanothus* and *arctostaphylos*. This study will make us know much about the dynamics of forest natural regeneration. Overall, fire is a catalyst for changing the species habit, biological diversity and stability. Studying from the seed-bank scale is the most basic for the further research.

Community scale

Fire is an importance disturbance and a controlling factor in community dynamics. The study of community dynamic was often based on the species character. Keeley (1981) analyzed the post-fire regeneration of southern California chaparral. The rate of shrub recovery varies depending on several factors. A major one is the reproductive mode of the dominant shrubs (keeley 1981; Sampson 1944). Other factors that affect shrub recovery include latitude, elevation, topography, slope, aspect, and weather patterns (Keeley 1981; Hanes 1977). Zhou (1988) put forward that people could play positive role in forest restoration, such as directly seeding, according to the ecological character of vegetation community like composition, distribution, growth and regeneration of forest. Shu (1993) studied the forest succession status at different burned degree in different areas from community scale and established a forest succession model according to different trend of vegetation succession. He considered that forest fire succession is comparatively prevalent in Daxing'an Mountains forest region, and it comprises primary succession, secondary succession, progressive succession and regressive succession. He thought that the forest community succession in Daxing'an Mountains at different geographic position reflects the succession time-order, and indicated that conflagration and repeated burn could induce degrading succession from larch-forest to broadleaved-forest. If broadleaved-forest suffers fire, it will degrade further to grassland. In addition, he also studied the influence of the changes of different environment factors such as the weather condition, swamp and the number of animals (Shu 1993) after fire on natural regeneration. Xiang (1990) studied the impact of fire severity on post-fire forest development in Daxing'an Montains, and believed that the natural restoration of vegetation was profoundly influenced by the fire severity. The severe burn is not beneficial to the vegetation restoration and growth, and in the severe burn area, artificial restoration must be made. Light burn could clear away some of the duff on the ground, which could make seeds touch the soil, and increase the nutritional elements in the soil.

Ecosystem scale

Fire induces change in ecosystem processes such as energy flow and nutrient cycling. Zhou Yiliang emphasized especially in his research that burned blank restoration should be studied from a relatively larger scale. Forest ecosystem management should be considered as a whole in keeping trees, shrubs, and grass at a reasonable proportion. Therefore it is not enough to restore forest only on burned blanks. Other vegetation components must be also reasonably restored (Zhou *et al.* 1989). Yang *et al.* (1992) studied the influence imposed on the cycle of nutritional elements in forest ecosystem by forest fire, which can be used to predict trend of vegetation restoration on burned blanks.

Landscape scale

Fire is a major player at the landscape level and has an important role in creating habitat diversity in the forest. The forest landscape is a complicated forest ecosystem composed of heterogeneous forest communities or forest types in a given area. It can be divided into two components, forest tree and forest environment by function and divided into many forest ecosystem units by territory. The dynamic change of forested landscape means dynamic change's summation of these forest units under different environment conditions (Shao *et al.* 1991). We can analyze the influence of natural landscape element and find out the forest dynamic in a broad scale. Also with the help of advanced technology, we can get the spatio-temporal information in an immediate time. Turner (1997) studied the reaction of vegetation in different burned area according to incrustation structure after forest fire in Yellowstone National Park. Moreover, by analyzing fire intensity, age of trees, and geographical location, she found that the size of fire and spatial structure had important and sustaining influence on vegetation restoration, but occurrence of these landscape scale influence was controlled by larger scale gradients. Xu *et al.* (1997) studied the status of forest fire and its influence on landscape structure by setting up sample plots and investigated large number of scared trees. He considered Landscape Ecology as an important theory basis for the management of forest resources. The main research scope now is to build simulation model of landscape dynamics based on vegetation change analysis under natural condition and human disturbance. Another point is to study the influence of spatial structure on forest restoration in terms of some key factors, such as slope, elevation and seed-bank, etc., on the burned blanks of Daxing'an Mountains region.

In a word, the study in the four scales had no absolute bound and each had advantage and disadvantage. Therefore, the combine of them could promote the research on the forest restoration in the burned blanks.

Research technology

With the development of modern technology, such as GIS & Remote Sensing, the study on vegetation restoration on burned blanks became much universal, and also showed high efficient. Simulation models at landscape

scale also increased predictability of forest development trend and extrapolated the research results more widely.

As early as in the 1970s, many studies were focused on the change of all kinds of forests caused by forest fire by using remote sensing technology, хурЯеВ. В.В (Xun *et al.* 1997) discussed the statistical method of burned-blank area by using different age, season and scale aerial photographs in 1974-1979, and delineated forest stand maps after forest fire by using satellite images and other spatial data in 1983. Jakubauskas (1990) derived vegetation type maps from remotely sensed data of 1974-1982. Then he evaluated vegetation change of Missigen pine-forest caused by forest fire in forested landscape by using "GIS" technology. In 1995, Gao *et al.* (1995) carried out investigation of regeneration and ecological changes on old burned blanks of *Pinus Yunnanesis* by remote sensing in Panxi, analyzed the spatial distribution and change law of ecofactors, determined the ecofactors and evaluation criteria, and finally set up a remote-sensing monitoring and evaluation model for ecological changes after forest fire.

Landscape process simulation at large scale is an important task in the domain of Landscape Ecology. He, H.S. (1999) studied forested landscape dynamic after forest suffered the disturbance of fire, wind-throwing and harvesting, and established a stochastic spatial simulation model for forest-landscape process involving fire disturbance and succession. The model indicates that there are some feedbacks between seed-bank, disturbance and environment, which cause the reappearance of characteristic landscape patches. The stochastic model is mainly used to study forest restoration after many times of forest fire in a long period, while mechanics model is mainly used to study one-off forest distribution in a relatively short period (He *et al.* 1999).

Forest fire is the regulator for forest ecological balance (Thompson *et al.* 2000). It is well accepted to use tree growth-ring data in studying vegetation restoration on burned blanks. The charcoal named as "fire fossil" is conserved in sediments widely, so it can provide a continuous data of fire in the past hundreds or even thousands of years. In combination with spore analysis, the analysis for charcoal has become an important method in studying the relationship between forest fire and environment. Chen (1990) studied the fire frequency with time-sequence and mathematics simulation, through spore-power and analysis of sediments in Bailing Lake of Australia in the early Holocene. The correlation between forest fire and main component of vegetation, as well as forest succession was delineated. Tinner (1999) used this method to analyze two lakes in south Sweden and found that forest fire played a very important role in vegetation composition 7000 years ago. He also found that forest fire decreased farina diversity, caused the extinction of some less enduring plants and changed the succession of vegetation community. Grogan *et al.* (2000) studied the influence of '*bishop pine*' Carbon-cycle in forest fire, and pointed out that "Redistribution of surface ash after fire by wind or water may cause substantial heterogeneity in soil N availability to plants, and may be an important mechanism contributing to vegetation patchiness in fire-prone ecosystem".

Strategies for forest restoration

Natural succession

Li *et al.* (2000) established a natural restoration model of hypo-growing forest on burned blanks, which can explicitly predict tree number on different types of site, thus adjusting the unreasonable distribution. Guan and Zhang (1989) studied the vegetation restoration in different types of sample plots in second year after forest fire in Daxing'an Mountains. By comparing burned plots with unburned one in the same types of vegetation, they also explored the likelihood of vegetation restoration with quantitative method.

Human interfered restoration

It refers to effectively shorten restoration cycle by increasing surviving ratio particularly in the area with poor soil conditions. In 1987, Prof. Zheng Huanneng put forward his forest combination cycle theory, which clarified the correlation among factors from the type of combustibility, fire ignition, fire environment and fire behavior. And he proposed some strategies for forest restoration (Zheng *et al.* 1987). Yang *et al.* (1989) investigated the forest restoration on the burned blanks of northern Daxing'an Mountains, and concluded that people must adjust their measures to local conditions. Forest is a vegetation community on the course of dynamic succession, and forest change can be classified into droughty series, mesic series and damp series, according to its spatial distribution and the phase of restoration. At present, for the site of mesic series, the artificial regeneration should be taken as key measures, and vegetation restoration should be taken for droughty series. They suggested that planting trees should be on the basis of understanding the ecological character of young larch tree and confirmed the methods of land coordination according to soil physical characters. Song and Yang (1996) put forward the concepts of "effect zone" and "effect island", which means to plant man-made needle forest on burned blanks according to the theory of marginal effect, for forming mixed forest with the natural broadleaved forest.

Prospect

The research of vegetation restoration on burned blanks is coming into a new era with the extensive appliance of modern science and technology. The developing trend of vegetation restoration research on burned blanks can be described as follows.

1). International cooperation is now being widened continuously. In recent years, international cooperation and

communion is getting more important and convenient with the development of information.

2). Unite micro and macroscale research, and emphasize more on macroscale research. The research subjects expand from the level of individual, seeding, community and ecosystem to landscape. The combination will be useful for people to understand the mechanism of the forest dynamics after fire.

3). Pay attention to the appliance of modern science and technology to vegetation restoration, and establish dynamic forecasting model.

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